(12) UK Patent Application (19) GB (11) 2 099 519 A

(21) Application No 8116764
(22) Date of filing 2 Jun 1981
(43) Application published 8 Dec 1982
(51) INT CL[3] F04B 49/00 F03C 1/00 F04B 3/00
(52) Domestic classification F1W 100 108 204 500 510 GB
(56) Documents cited
GB 0890963
GB 0880631
GB 0875505
GB 0567502
GB 0500569
GB 0479550
GB 0476953
GB 0410811
GB 0336810
(58) Field of search F1W
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(54) A variable displacement pump or fluid motor

(57) A variable displacement pump or fluid motor comprises an arrangement of sets of cylinders (8) and pistons (1, 2), each set comprising two cylinders and two pistons, the two cylinders being connected together exclusively by an individual connecting fluid chamber (7) forming, together with one piston accommodated in each cylinder, a single fluid space communicating with an external fluid system via flow control valves (3, 4) located in the wall of the fluid space. Variable displacement is obtained by causing the pistons to reciprocate at constant stroke length and equal frequency in a controllable variable phase relationship by a differential motion mechanism. A single pump may contain one set or a plurality of sets of cylinders and pistons. The pump is capable of functioning as a motor in response to reverse pressure applied at the inlet and outlet valves except at the extreme condition of zero displacement.

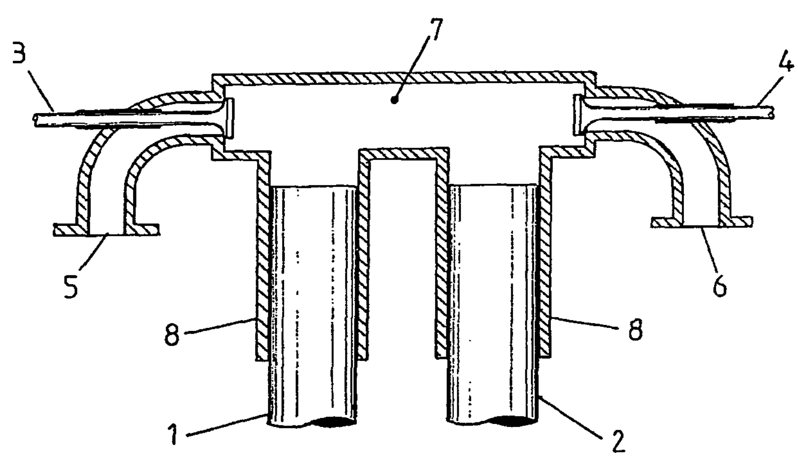

Fig. 1

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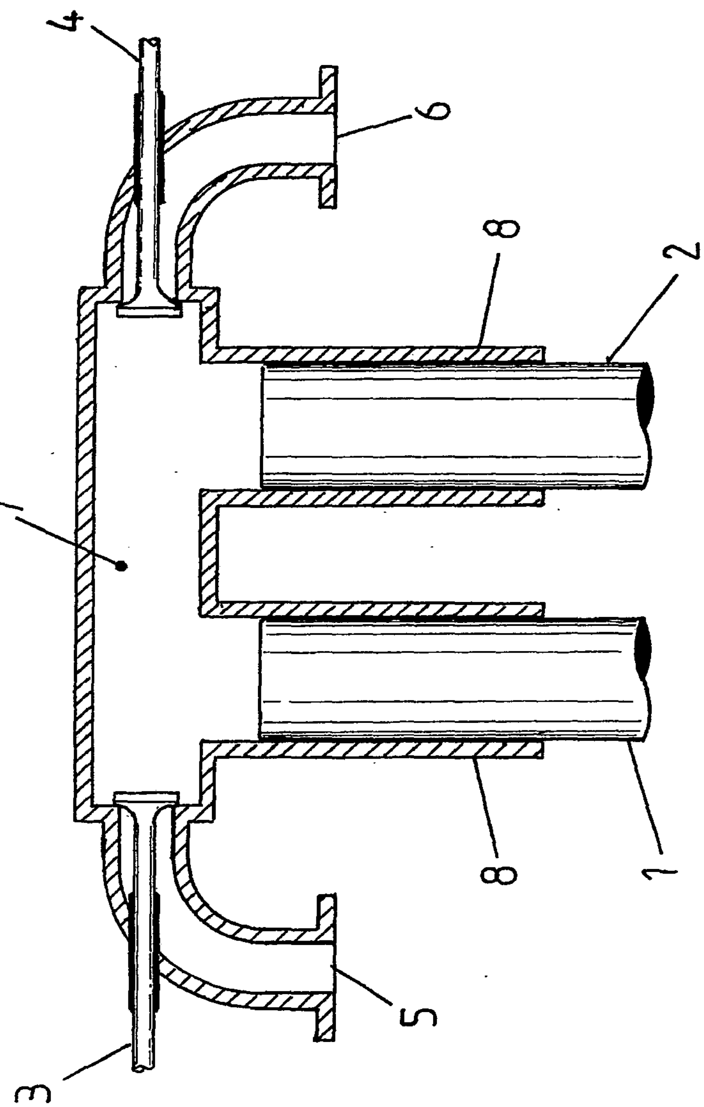

Fig.1

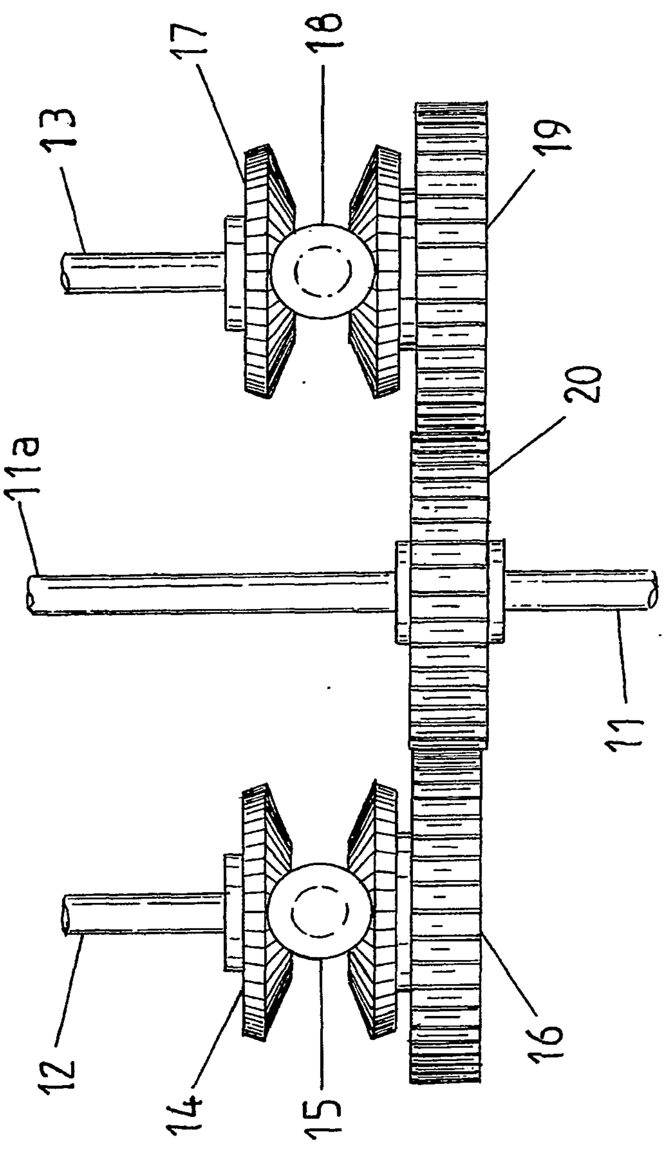

Fig. 2

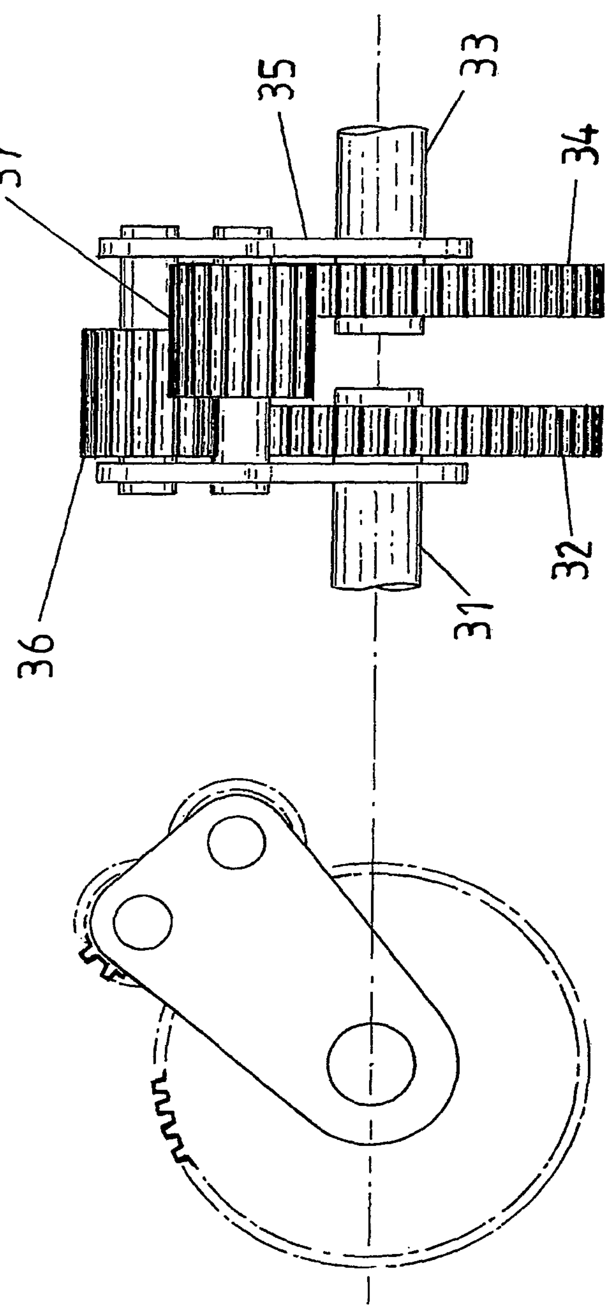

Fig. 3

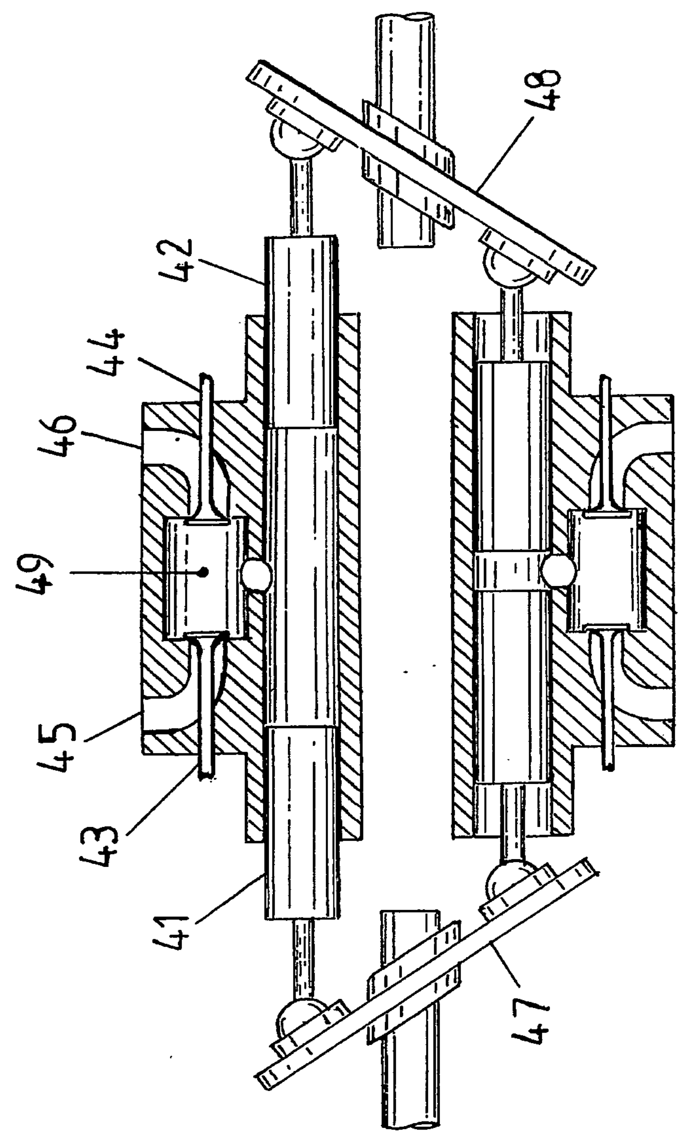

Fig. 4

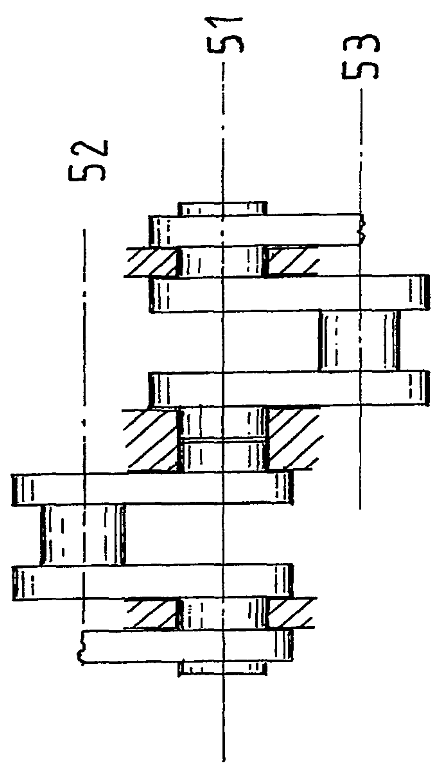

Fig.5

SPECIFICATION

A variable displacement pump or fluid motor

This invention is a variable displacement pump having an infinitely variable fluid volume throughput at the inlet and outlet ports per revolution of the mainshaft, ranging from zero throughput to maximum capability. The pump is also capable of functioning as a motor and also capable of changing function from pump to motor or vice versa at any time in response to changing load conditions.

Interfacing

The pump interfaces with any associated system via a rotating power shaft, inlet and outlet fluid ports, control inputs in the form of mechanical linkages, and structural attachments (mountings).

Prior Art

The invention relates to all forms of pumps or fluid motors which have reciprocating pistons linked to a rotating member or members by some form of eccentric connection embodied in the rotating member or members, and relates also to differential gear trains based on epicyclic forms of gear train in which there are three significant motional elements, where the motion of any one such element is the resultant of the combined motions of the two remaining significant motional elements.

Application

The pump is intended for use in power transmission systems, where, in association with other equipment it provides for an infinitely variable speed relationship between rotating power shafts. In particular it is suitable for use in an energy conservation system where kinetic energy is transferred between energy storing devices in a reversible manner, for example, between a vehicle and a flywheel carried by the vehicle.

Method of Obtaining Variable Displacement

Variable displacement is obtained by an arrangement of "complementary pairs" of pistons which have a controlled variable phase relationship. Fig. 1 is a diagrammatic representation of a pair of complementary pistons, 1 and 2, accommodated in a pair of cylinders which are in constant fluid communication with each other via a connecting fluid chamber 7, and communicating otherwise with the external fluid circuit only, via flow control valves 3 and 4 located in the said fluid chamber, and the inlet and outlet fluid ports 5 and 6. Referring to Fig. 1, pistons 1 and 2, equal in diameter, are caused to reciprocate (by means not shown) in simple harmonic motion at equal and constant amplitude (stroke length) and equal frequency but with a controlled variable phase relationship. When pistons 1 and 2 reciprocate absolutely in phase (zero phase difference) the cyclic volume throughput is equal to the sum of the individual displacements of the two pistons. As phase difference is increased progressively from zero the volume throughput decreases progressively until at 180 degrees phase difference, throughput is zero. At 180 degrees phase difference the displacement of one piston is accommodated within the cylinders by the displacement of the complementary piston.

For a pump, not required to motor, simple non-return valves at locations 3 and 4 in Fig. 1, will control direction of flow and ensure a useful system. When used in a motor, flow control valves must be positively actuated in relation to the positions of the two pistons.

Valve Timing

When pistons 1 and 2 are reciprocating exactly in phase the operating points for opening and closing valves are top dead centre and bottom dead centre of piston stroke, as is well established in conventional fluid motor practice.

When there is a phase difference between complementary pistons the valve operating points occur respectively midway between the two top dead centre positions of the two complementary pistons and midway between the two bottom dead centre positions of the two complementary pistons. Phase relationships between complementary pistons are measured in terms of angular relationships between associated rotary members. Phase difference is limited to 180 degrees, therefore, except at 180 degrees it is always the smaller of the two angles measurable between complementary pistons. If for example, this phase angle is 10 degrees then the valve operating points occur respectively 5 degrees after the leading piston reaches top dead centre and 5 degrees after the leading piston reaches bottom dead centre. This ratio applies throughout the full range of phase difference, thus at 180 degrees phase difference, the valve operating points occur when both piston are at mid-stroke.

Valve operating points are the "effective top dead centre" and "effective bottom dead centre" of the complementary pair of pistons. Effective top dead centre occurs when both pistons are equidistant from the individual top dead centre and either coinciding with the point of piston mid-stroke or are on the side of mid-stroke nearer to individual top dead centre. Effective bottom dead centre occurs when both pistons are equidistant from the individual bottom dead centre and either coinciding with the point of piston mid-stroke or are on the side of mid-stroke nearer to individual bottom dead centre. Effective top dead centre and effective bottom dead centre are the points, respectively, of minimum and maximum volume of the pair of complementary cylinders for a given phase difference of the relation pistons.

Phase Control Mechanism

The controlled variable phase relationship between complementary pistons, and the actuation of associated flow control valves is achieved by generating the required phase

relationship in a toothed gear train which interfaces within the pump via three rotating shafts, dipicted diagrammatically in Fig. 2.

Referring to Fig. 2, shaft 11 is the mechanical input/output element of the pump, keyed to spur gear wheel 20 and extending through gear wheel 20 to drive the valve operating mechanism of the pump at 11a. Meshing with 20 are compound spur and bevel gear wheels 16 and 19. Bevel pinion 15 meshes with compound gear wheel 16 and with bevel gear wheel 14. Bevel pinion 18 meshes with with compound gear wheel 19 and with bevel gear wheel 17. 14 is keyed to shaft 12. 17 is keyed to shaft 13. Shafts 12 and 13 connect respectively to two rotary members within the pump.

Bevel pinions 15 and 18 are mounted respectively in two carriers (not shown in Fig. 2), one carrier is rotatable about the projected axes of 14 and 16, which are coincident, the other carrier is rotatable about the projected axes of 17 and 19, which are coincident. Each bevel pinion is attached to its carrier by the bevel pinion shaft. The carrier supports the bevel pinion and maintains precise contact between the bevel pinion and its mating gear wheels.

If gear wheel 16 is held stationary while shaft 12 is rotated by a small amount, bevel pinion 15 will orbit in contact with its mating gear wheels around the projected axes of 14 and 16 taking with it the bevel pinion carrier. The angular displacement of the bevel pinion carrier will be equal to half the angular displacement of shaft 12. Alternatively, if the bevel pinion carriers are both held stationary and shaft 11 is rotated in steady state the whole of the gear train will rotate except for the bevel pinion carriers. In this steady state, limited superimposed rotation of the bevel pinion carriers will effect a phase change in the angular relationships of shafts 11, 12 and 13. Thus, by controlled limited rotation of the bevel pinion carriers the required control of phase relationships between pistons and flow control valves may consequently be achieved.

Regarding the gear train of Fig. 2 as comprising three sub-assemblies arranged respectively on the centre-lines of shafts 11, 12 and 13, the order of these sub-assemblies may be changed to effect a change in the relative directions of rotation of the said shafts. In particular shafts 12 and 13 may be arranged to counter rotate with respect to each other. One or more intermediate gear wheels may be included in the gear train.

Control Inputs

Rotation of the bevel pinion carriers for controlling phase difference between the three shafts 11, 12 and 13 is by mechanical linkage capable of reacting the working loads and designed to achieve the required phase relationships between the three shafts. The input linkage to the bevel pinion carriers is selectively positioned in response to pump (or motor) performance demand and may be power assisted as necessary. Control parameters for the pump (or motor) may be shaft speed or shaft torque, possibly derived from performance demands on the associated system. Performance may be sensed and regulated by human operation or may be sensed by instruments and may be wholle or partly under automatic control.

Referring to the examples of Fig. 1 and Fig. 2, the three interfacing shafts of the gear train (11, 12 and 13 in Fig. 2) provide the necessary driving elements for the pistons (via suitable linkage), and for the flow control valves.

Multi-Cylinder Configurations

The basic arrangement of complementary cylinders and pistons is suitable for building into multi-cylinder in-line or radial configurations having regard to the requirement for two rotating members to serve the two groups of pistons which result from connecting one piston from each complementary pair of pistons to one rotating member and the other piston from each complementary pair of pistons to the other rotating member.

Radial Cylinder Rotary Pump

A variation of the radial cylinder pump is the radial cylinder rotary pump in which radially disposed cylinders rotate as a block about a stationary eccentric member which may be a crankpin, or cam, or roller or any other eccentric device found satisfactory in the art.

The system of complementary cylinders and pistons can be applied to the rotary pump. A minimum of two rows of cylinders are required to accommodate the complementary pistons, a row of cylinders being defined as a plurality of cylinders arranged radially with respect to the pump axis entirely in a plane extending everywhere at right angles to the pump axis. The otherwise stationary eccentric members, one for each row of pistons, must be rotatable over a limited arc to provide for control of the variable phase relationship of complementary pistons. Eccentric members each have two axes, the first axis coincides with the main axis of the pump, the second axis is parallel to the first axis at a distance depending upon particular design. The locus of the second axis is movable in an arc about the first axis. Fig. 5 is a diagrammatic representation of a plan view of a pair of eccentric members, in this case a pair of cranks. In Fig. 5, 51 is the centre-line of the first axes of both cranks. The second axes are respectively, 52 and 53 which are the centre-lines of the crankpins. As viewed in Fig. 5, all axes lie in the plane of the paper which is the limiting position of 180 degrees phase difference between the eccentrics. At zero phase difference between eccentrics the second axes of the eccentrics (52 and 53) are mutually aligned. The range of rotation of each eccentric member is 90 degrees. The mechanism for rotating the eccentric members is required only to rotate the eccentric members in opposite directions over an arc of 90 degrees each, from coincidence to a phase difference of 180 degrees and to react the

working loads. Actuation of flow control valves is aligned to the rotating cylinders and requires no adjustment for phase variation between complementary pistons.

The advantage of the relative simplicity of the eccentric member actuating mechanism for the rotary pump is offset by the complication of transferring fluid between the rotating cylinder block and the external fluid circuit.

Swashplate Pump

The swashplate type, or axial type of pump is suitable for the application of the system of complementary pistons. Two similar swashplate pumps are mounted head to head as illustrated diagrammatically in Fig. 4, with opposing pistons 41 and 42 and their associated cylinders arranged as complementary pairs along common axes having an individual connecting fluid chamber 49 for each complementary pair of cylinders, each such fluid chamber being connected to the external fluid circuit via flow control valves 43 and 44 and inlet and outlet fluid ports 45 and 46. Each swashplate, 47 and 48, has a constant geometrical relationship with its individual power shaft, and opposing pistons have equal displacement. Control of collective phase relationships of pistons and flow control valves, and transmission of power is via some form of differential motion assembly as described herein, connected to the two rotary members, which, in this case are the individual power shafts for each swashplate, and to the valve actuating mechanism.

Opposed-Piston Type Pump

In the conventional opposed piston pump, two pistons reciprocate in a continuous cylinder, or a pair of cylinders connected by a common fluid chamber, along a common axis with piston crowns confronting. The pistons approach and recede to and from each other in a constant phase relationship and in constant fluid communication with each other. Flow into and out of the fluid space between the two piston crowns is controlled by valves which have a common effect in relation to both pistons. The opposed piston pump may have one pair of opposed pistons or a plurality of pairs of opposed pistons.

For variable displacement, each pair of opposed pistons can be regarded as a complementary pair with a differential motion assembly, as described herein, providing the means of controlling collective phase relationships of complementary pistons and valve actuation.

Differential Motion Assemblies

Referring to Fig. 2, the partial gear train comprising the compound spur and bevel gear wheel 16, the bevel pinion 15 and its carrier and the bevel gear wheel 14 and shaft 12 is a form of epicyclic gearing which is characterised by having three significant motional elements where the motion of any one of these elements is the resultant of the combined motions of the other two. In this case the significant motional elements are the compound gear wheel 16, the bevel gear wheel 14 and the bevel pinion carrier. It follows that in any differential motion assembly of this type that any one of the significant motional elements may be used as the control element for governing the motional relationship of the two remaining significant elements.

Another form of epicyclic gearing which may be used as a differential motion assembly is shown diagrammatically in Fig. 3 which illustrates a spur gear differential motion assembly in which shaft 31 (keyed to gear wheel 32) and shaft 33 (keyed to gear wheel 34) and the carrier 35 (supporting pinions 36 and 37) are the three significant motional elements.

The planet gear wheels (or orbital gear wheels) in the differential motion assemblies described herein may be multiplicated if required for the purpose of balancing or for meeting load conditions.

The differential motion assemblies described are suitable for controlling phase relationships between any number of shafts by suitable compounding.

Where the variable displacement pump is intended for use as a pump only with no requirement to motor, flow control valves may be designed to operate by fluid pressure only, in which case phase control is required only for the pistons and a simple three element differential motion assembly will suffice.

This present invention is concerned primarily with a variable flow capability extending to a lower limit of zero flow which requires that each piston of a complementary pair must have equal displacement, which may be obtained by an equal value of the product of piston stroke and the square of piston diameter. Where it is required to have a lower limit of variable flow of some finite value, displacement of complementary pistons may be unequal, according with the particular requirements.

Mode of Reciprocation

The argument hereinbefore regarding the performance of complementary pistons is based on specified simple harmonic motion. Departure from simple harmonic motion is tolerable in the case of complementary pistons to the same extent as is tolerable in conventional piston performance.

Diaphragm Pump

Any reference to pistons in this specification is applicable equally to the flexible disphragm type of pumping element.

CLAIMS

1. A variable displacement pump wherein variable displacement is obtained by a method of varying the phase relationship between two complementary pistons which reciprocate at constant stroke length being actuated via suitable linkage from a power source; the two complementary pistons reciprocate at equal

frequency except during transition from one phase relationship to another; the two complementary pistons are accommodated respectively one in each of two complementary cylinders, the said cylinders being connected together in the region of each cylinder head by a fluid chamber, the two complementary pistons together with the two complementary cylinders and the connecting fluid chamber together with flow control valves located in the wall of the fluid space collectively form a continuous enclosed space which contains the working fluid, communication between the said enclosed space and an external fluid system is via the said flow control valves.

2. A variable displacement pump as claimed in claim 1 with additional access to the enclosed fluid space for instrumental or pressure relief or sampling means.

3. A variable displacement pump as claimed in claims 1 and 2 wherein each flow control valve is actuated by differential fluid pressure.

4. A variable displacement pump as claimed in claims 1 and 2 wherein the flow control valves are mechanically operated in a specified relationship with the motion of the two complementary pistons.

5. A variable displacement pump as claimed in claims 1, 2, 3 and 4 wherein is embodied a differential motion mechanism comprising a first shaft keyed to a bevel gear wheel, a bevel pinion meshing with the said bevel gear wheel, a second bevel gear wheel meshing with the said bevel pinion the second bevel gear wheel being keyed to a second shaft, the projected axes of the first and second shafts are coincident, the bevel pinion is supported by a carrier which is rotable over a limited angle about the projected axes of the first and second shafts, causing the bevel pinion to orbit relative to the said bevel gear wheels within a limited angle, selective positioning of the bevel pinion carrier controls the phase relationship between the said first and second shafts; if required the bevel pinion may be supplemented by one or more similar bevel pinions similarly supported by the carrier.

6. A variable displacement pump as claimed in claims 1, 2, 3 and 4 wherein is embodied a differential motion mechanism comprising a first shaft keyed to a spur gear wheel, a pinion meshing with the said spur gear wheel and meshing also with a second pinion, the second pinion meshing also with a second spur gear wheel which is keyed to a second shaft, the projected axes of the first and second shafts are coincident, the two pinions are supported in a carrier and are constrained to orbit the said spur gear wheels over a limited arc, selective positioning of the pinion carrier controls the phase relationship between the first and second shafts; if required the pair of pinions may be supplemented by one or more similar pairs of pinions similarly supported in a common carrier.

7. A variable displacement pump as claimed in claims 1, 2, 3, 5 or 6, wherein a source for piston actuation is provided by a powered shaft which transmits motion direct to the actuation system of one of the complementary pistons and via gearing transmits motion to the first shaft of a differential motion mechanism according to claims 5 or 6 whereby motion is transmitted to the actuation system of the other complementary piston suitably modulated with respect to any desired phase relationship between the two complementary pistons.

8. A variable displacement pump as claimed in claims 1, 2, 4, 5 or 6, wherein a source for piston actuation and valve actuation is provided by a powered shaft providing input motion to a gear train having three output shafts, one output shaft transmits motion direct to any chosen piston or valve actuation system, the remaining two output shafts serve as first shafts or transmit motion to the first shafts of two differential motion mechanisms according to claims 5 or 6 whereby the motion is transmitted respectively to the remaining piston and/or valve actuation system suitably modulated with respect to any desired phase relationships between the complementary pistons and the actuation of the flow control valves.

9. As claimed in any preceding claim, a variable displacement pump comprising a plurality of complementary pairs of cylinders and pistons in which one piston in each complementary pair of pistons is connected to a first piston actuation system and the other piston in each complementary pair of pistons is connected to a second piston actuation system; where embodied, mechanically operated flow control valves are actuated collectively by the valve actuation system; within each of the three said actuation systems all components have a constant phase relationship; the variable phase relationships between actuation systems are varied collectively and evenly as required.

10. A variable displacement pump as claimed in claims 1, 2, 3, 4 and 9, wherein a plurality of radially disposed complementary pairs of cylinders and pistons rotate as a whole around an eccentric actuation system, the said eccentric actuation system providing the means for reciprocation of the pistons and for obtaining and controlling the variable phase relationship between complementary pistons by means of limited rotation of the eccentric elements in the actuation system as required.

11. A variable displacement pump as claimed in claims 1, 2, and 4 to 10 inclusive, wherein while no power is input at the pump power shaft from an external source, reverse pressure applied at the pump inlet and outlet ports causes the pistons to reciprocate enabling the pump to function as a motor except when the phase difference between complementary pistons is exactly 180 degrees.

12. A variable displacement pump substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

New claims filed on 7/12/81.
Superseded claims 1—12.
New claims:—

1. A variable displacement pump wherein variable displacement is obtained by a method of varying the phase relationship between two complementary pistons which reciprocate at constant stroke length being actuated via suitable linkage from a power source; the two complementary pistons reciprocate at equal frequency except during transition from one phase relationship to another; the two complementary pistons are accommodated respectively one in each of two complementary cylinders, the said cylinders being connected together in the region of each cylinder head by a fluid chamber, the two complementary pistons together with the two complementary cylinders and the connecting fluid chamber together with flow control valves located in the wall of the fluid space collectively form a continuous enclosed space which contains the working fluid, communication between the said enclosed space and an external fluid system is via the said flow control valves which are mechanically operated in a specified phase relationship with the complementary pair of pistons, input motion to the pump is via a differential motion mechanism which accepts input motion via a single shaft and disributes that motion via gearing to three further shafts connected respectively one to each piston actuating mechanism and one to the valve actuating mechanism, the differential motion mechanism generates the required phase relationships between shafts according to performance demands upon the pump.

2. A variable displacement pump as claimed in claim 1 wherein is embodied a differential motion mechanism comprising a first shaft keyed to a bevel gear wheel, a bevel pinion meshing with the said bevel gear wheel, a second bevel gear wheel meshing with the said bevel pinion the second bevel gear wheel being keyed to a second shaft, the projected axes of the first and second shafts are coincident, the bevel pinion is supported by a carrier which is rotatable over a limited angle about the projected axes of the first and second shafts, causing the bevel pinion to orbit relative to the said bevel gear wheels within a limited angle, selective positioning of the bevel pinion carrier controls the phase relationship between the said first and second shafts; if required the bevel pinion may be supplemented by one or more similar bevel pinions similarly supported by the carrier.

3. A variable displacement pump as claimed in claim 1 wherein is embodied a differential motion mechanism comprising a first shaft keyed to a spur gear wheel, a pinion meshing with the said spur gear wheel and meshing also with a second pinion, the second pinion meshing also with a second spur gear wheel which is keyed to a second shaft, the projected axes of the first and second shafts are coincident, the two pinions are supported in a carrier and are constrained to orbit the said spur gear wheels over a limited arc, selective positioning of the pinion carrier controls the phase relationship between the first and second shafts; if required the pair of pinions may be supplemented by one or more similar pairs of pinions similarly supported in a common carrier.

4. A variable displacement pump as claimed in claims 1, 2 or 3 wherein a source for piston actuation and valve actuation is provided by a powered shaft providing input motion to a gear train having three output shafts, one output shaft transmits motion direct to any chosen piston or valve actuation system, the remaining two output shafts serve as first shafts, or transmit motion to the first shafts, of two differential motion mechanisms according to claims 2 or 3 whereby the motion is transmitted respectively to the remaining piston or piston and valve actuation systems suitably modulated with respect to any desired phase relationships between the complementary pistons and the actuation of the flow control valves.

5. A variable displacement pump as claimed in claim 1 comprising a plurality of complementary pairs of cylinders and pistons in which one piston in each complementary pair of pistons is connected to a first piston actuation system and the other piston in each complementary pair of pistons is connected to a second piston actuation system; the mechanically operated flow control valves being actuated collectively by the valve actuation system; within each of the three said actuation systems all components have a constant phase relationship; the variable phase relationships between actuation systems are varied collectively and evenly as required.

6. A variable displacement rotary pump in which a plurality of radially disposed pairs of complementary cylinders and pistons arranged in one or more double rows rotate as a whole around a fixed axis, each two adjacent cylinders one in each row of a double row being connected together by an individual fluid chamber to form a complementary pair of cylinders, each fluid chamber communicating with an external fluid circuit via transfer ports to provide inward and outward flow to and from the cylinders; each piston is caused to reciprocate relative to its associated cylinder by an eccentric connection a separate eccentric connection being provided for each row of pistons, controlled variable displacement being obtained by controlled variation of the relative angular incidence of the two eccentric members associated with each double row of pistons, the essential phasing of fluid transfer via the transfer ports in relation to piston motion is also governed by the angular positioning of the eccentric members.

7. A variable displacement pump as claimed in claims 1, 5 and 6 wherein while no power is input at the pump power shaft from an external source, reverse pressure applied at the pump inlet and outlet ports causes the pistons to reciprocate

enabling the pump to function as a motor except when the phase difference between complementary pistons is exactly 180 degrees.

8. A variable displacement pump substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1982. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained